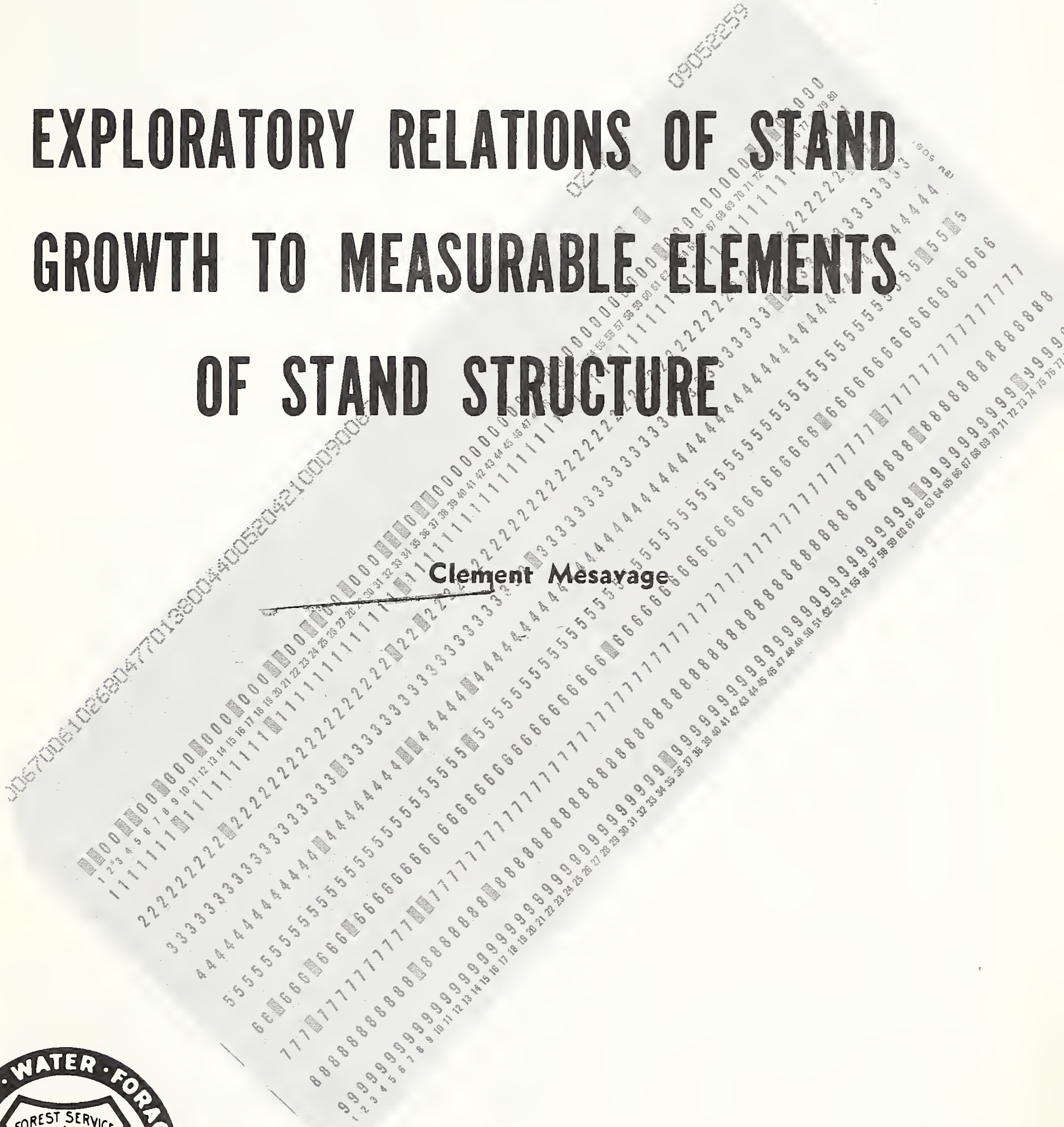
Occasional Paper 182

1961

EXPLORATORY RELATIONS OF STAND GROWTH TO MEASURABLE ELEMENTS OF STAND STRUCTURE



Clement Mesavage

SOUTHERN FOREST EXPERIMENT STATION
PHILIP A. BRIEGLEB, DIRECTOR
Forest Service, U. S. Department of Agriculture

An exploratory study with shortleaf pine (*Pinus echinata* Mill.) in north Arkansas indicates that variations in basal area growth may be strongly correlated with measurable elements of stand structure. This possibility was studied to reduce the time needed to assess the desirability of alternative forest cutting practices, to make possible growth predictions based on data normally collected by forest inventories, to provide timber markers with guides to future tree behavior, and, ultimately, to permit linear programming aimed at predicting the structure best calculated to achieve a specified objective given various cost-price assumptions and an initial structure.

PLAN OF STUDY

Twenty-seven one-acre plots installed in 1956 provided a controlled range in sawtimber stocking, tree diameter, and space occupied by pines of sawtimber size. Other variables included age in several forms, data pertaining to the density and size of various stand components (such as growing stock, ingrowth reservoir, etc.) competition, and other factors (table 1).

Table 1.—*Independent variables available for regression analysis*

X_1	Number of residual pines per acre, larger than 3.5 inches d.b.h.
X_2	do. , larger than 7.5 inches
X_3	do. , from 6.6 to 7.5 inches
X_4	Sum of residual diameters (inches per acre), pines 0.6 to 3.5 inches
X_5	do. , pines larger than 3.5 inches
X_6	do. , pines 3.6 to 6.5 inches
X_7	do. , pines 3.6 to 7.5 inches
X_8	Sum of residual basal areas (square feet per acre), all species, 0.6 to 3.5 inches
X_9	do. , pines 3.6 to 7.5 inches
X_{10}	do. , pines larger than 3.5 inches
X_{11}	do. , pines larger than 7.5 inches
X_{12}	Squared sum of basal areas of residual pines larger than 7.5 inches
X_{13}	Mean age of pine dominants
X_{14}	Reciprocal of mean age of pine dominants
X_{15}	Mean age of pines larger than 7.5 inches
X_{16}	Coefficient of variation about mean age, pines larger than 7.5 inches
X_{17}	Mean diameter of residual pines larger than 3.5 inches
X_{18}	Coefficient of variation about mean diameter, pines larger than 7.5 inches
X_{19}	Coefficient of variation of basal-area spatial distribution (7-diopter point samples)
X_{20}	Percent of live crown length, residual pines larger than 7.5 inches
X_{21}	Index to recent cutting: residual pines larger than 3.5 inches after recent cutting divided by total basal area (all species 0.6 inch and larger) present prior to recent cutting
X_{22}	Index to recent cutting: 100 times the reciprocal of 1 plus the ratio of basal area of residual pines and hardwoods to basal area of cut pines and hardwoods (in each case only pines larger than 7.5 inches and hardwoods larger than 6.5 inches are included)
X_{23}	Basal area removed in recent cutting
X_{24}	Mean height of pine dominants divided by mean age in years
X_{25}	Site index (mean height of dominants at age 50 years)
X_{26}	10-year radial growth of pine dominants, in inches

Gross basal-area growth of sawtimber and cordwood, including mortality, was determined by stand remeasurement after two growing seasons.

ANALYSIS

The Southern Forest Experiment Station's IBM 704 Regression Program was employed in the analysis. Regression program outputs, each yielding regression coefficients and the variation accounted for by 511 regressions (one for every possible linear combination of the 9 or fewer independent variables), were obtained for two-year basal-area growth of the following:

(a) Pine cordwood and sawtimber component (survivors plus ingrowth), 3.6 inches d.b.h., threshold diameter.

(b) Pine sawtimber component (survivors plus ingrowth), 7.6 inches d.b.h., threshold diameter.

(c) Pine sawtimber component (survivors only).

Several exploratory selections of independent variables were made, and separate regression outputs were obtained for each selection.

Dependent and independent variables selected for each output are shown in table 2.

Table 2.—*Squared multiple correlation coefficients (R^2) for several regression analyses*

Dependent variable: two-year basal-area growth in square feet per acre	Independent variables selected for analyses	R^2 for 9 variables	Independent variables in "best" regression	R^2
Pine cordwood and sawtimber,				
survivors plus ingrowth (first output)	X_5 X_8 X_9 X_{11} X_{13} X_{17} X_{19} X_{20} X_{21}	.647	X_8 X_{13} X_{21}	.564
Pine cordwood and sawtimber, survivors plus ingrowth (second output)	X_1 X_4 X_5 X_{10} X_{13} X_{14} X_{19} X_{21} X_{24}	.635	X_1 X_{13}	.475
Pine sawtimber, survivors plus ingrowth (first output)	X_2 X_7 X_8 X_{11} X_{13} X_{18} X_{19} X_{23} X_{25}	.836	X_2 X_{13}	.795
Pine sawtimber, survivors plus ingrowth (second output)	X_2 X_3 X_6 X_{11} X_{12} X_{15} X_{16} X_{22} X_{26}	.824	X_2 X_{15}	.721
Pine sawtimber, survivors only	X_2 X_7 X_8 X_{11} X_{13} X_{18} X_{19} X_{23} X_{25}	.893	X_{11} X_{13}	.837

RESULTS

As table 2 indicates, the 9-variable regressions accounted for 65 percent of the variation in cordwood basal-area growth, 84 percent of the variation in sawtimber basal-area growth including ingrowth, and 89 percent of the variation in sawtimber basal-area growth excluding ingrowth. The most worthwhile regressions with fewer than 9 independent variables were easily screened from the remainder of the IBM 704 outputs. Residual mean squares from the 9-variable regressions were used as rough error terms to screen the difference in variation accounted for by the "best" 1-variable regression, the "best" 2-variable regression, etc., up to the full 9-variable regression. Value of F_{05} for degrees of freedom 1 and 17 (27 sets of observed values, less 10 degrees for data-derived constants) is 4.45, and any difference in sums of squares attributable to regression that was 4.45 times as large as the residual mean square seemed unlikely to be chance-caused. Sums of squares attributable to regression were given directly as a part of the IBM 704 program outputs.

The "best" regressions for predicting two-year basal area growth in square feet per acre were:

Pine cordwood and sawtimber, survivors plus ingrowth (first output) $= 0.272066\ X_8 - 0.220255\ X_{13} + 8.79020\ X_{21} + 9.65455$

Pine cordwood and sawtimber, survivors plus ingrowth (second output) $= 0.0112359\ X_1 - 0.176182\ X_{13} + 11.9865$

Pine sawtimber, survivors plus ingrowth (first output) $= 0.0297886\ X_2 - 0.190111\ X_{13} + 13.4249$

Pine sawtimber, survivors plus ingrowth (second output) $= 0.030790\ X_2 - 0.200788\ X_{15} + 13.3904$

Pine sawtimber, survivors only $= 0.0587584\ X_{11} - 0.137340\ X_{13} + 7.81012$

The importance of age in predicting growth on the study plots was unexpected. Average ages of dominant trees on a given plot ranged from 39 to 67 years Since a restricted age range of 39 to 48 years was present on 19 of the 27 plots, a separate regression output involving pine sawtimber (survivors plus ingrowth) was obtained for this group. Value of R^2 (the squared coefficient of multiple correlation) for the 9-variable regression was .8026 for the restricted range in age, compared with R^2 of .8362 for the corresponding regression involving all 27 plots. This difference supports the inference that age is important in accounting for growth differences on these plots even when oldest trees are excluded. The "best" regression for the 19 plots with a narrow range in ages also included mean age of dominant pines (X_{13}) and number of pines 7.6 inches d.b.h. and larger (X_2). The 19-plot R^2 involving X_{13} and X_2 was .707, as compared with an R^2 of .736 for the 27-plot regression involving the same two independent variables.

Unless age or some function of age was included with the independent variables, none of the regressions was significant at the .01 level. Several of the sawtimber growth regressions that lacked age, however, were significant at the .05 level, and might be of interest when it is impracticable to determine age. These were:

2-year basal-area growth in pine sawtimber, survivors plus ingrowth $= .101121\ X_2 - .00127480\ X_{12} + 4.74338\ X_{26} - 1.74492$

2-year basal-area growth in pine sawtimber, survivors only $= 0.0607037\ X_2 - .00186244\ X_7 + .0596870\ X_{11} + 2.76410$

DISCUSSION

Examination of the amount of variation that each independent variable accounted for, individually and in combination with others, shows that basal-area growth variations between stands can be satisfactorily attributed to measurable elements of stand structure. Further research is needed to determine whether other easily measured important independent variables can be discovered. In addition, it may be fruitful to investigate whether the accuracy of estimates can be improved by changing the functions of the variables used.

This study indicates that the following types of independent variables are more or less correlated with basal-area growth of shortleaf pine in the Arkansas Ozarks:

Some function of stand age.

Variables describing distribution in size and space of growing stock component including N, D, D^2, coefficient of variation of diameter, and coefficient of variation of basal-area spatial distribution.

Similar variables describing potential ingrowth components.

Similar variables describing competitive components (undesirable stems and desirable stems not contributing to survivor growth or ingrowth).

Variables describing severity of recent drastic reduction in tree population (due to cutting, TSI, windthrow, etc.).

Past growth.

Some specific findings in regard to choice of variables were as follows:

1. Age of dominant trees was a more useful variable than the reciprocal of age. For sawtimber growth, it was better than the mean age of sawtimber-size trees. The coefficient of variation of mean age improved the regression, but not significantly. Possibly, age of dominants may be best for use in predicting the growth of even-aged stands, and mean age of the growing stock components and the coefficient of variation of mean age may be best for uneven-aged stands (i.e., where larger coefficients of variation of age prevail).

2. Site index did not appear important in the presence of age, but did appear important in the absence of age. It is unfortunate that through accident there was a fairly strong nonsense correlation (negative) between site and age.

3. A curvilinear function of basal area appeared somewhat better in general than the simple linear form for explaining growth differences.

4. Number of trees per acre, or the sum of tree diameters, can under some circumstances be more important than basal area, and hence should be included as an expression of density. These terms seem to be particularly important for introducing the effect of ingrowth and competition, where the range of sizes is not great.

5. Probably because the stands were essentially even-aged, the coefficient of variation of diameter did not show up as an important element.

6. The regression outputs indicate that ingrowth tends to increase *directly* with coefficient of variation of growing space. When ingrowth is not included in growth estimates, growth of survivors appears to be *inversely* proportional to the same variable.

7. Competition was not important in the present study, because hardwoods larger than 3 inches d.b.h. had been killed on all plots before the measured growth period.

8. Effects of recent cuttings may be quite important in predicting growth, but the effect should lessen with the length of time since cutting.

9. Past radial growth may be a useful variable, but exploratory work is needed to ascertain whether some non-linear function of it might not be preferable, as well as to learn whether growth of dominants will suffice or whether the term should be broad enough to include past ingrowth.

In designing studies for predicting growth by regression analysis, it seems best to express growth in terms of basal area, since this measure will not be affected much by site variation, unless extreme. When predictions are in terms of volume growth, tree height is introduced as a variable that will fluctuate with site index, making the regression analyses more complex. Ultimately, when site-prediction regressions based on soil variables have been worked out, volume predictions based on both site and stand structure may be developed, but progress will be more rapid initially if each is studied separately.